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Article

Educational Escape Rooms as an Active Learning Tool for Teaching Telecommunications Engineering

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Abstract: Traditional education, particularly at a university level isn't necessarily very engaging or strong at building teamwork skills. Educational escape rooms are a recent game based learning approach which combines team based problem solving with a story-line and cryptic clues. In this paper we apply the concept of educational escape rooms to the telecommunications engineering classroom by creating a series of two separate scenarios, each containing three puzzles. Our evaluation is based on beta tester survey results which suggest that this will be an engaging and challenging tool for teaching telecommunications engineering. Although educational escape rooms are rapidly being deployed in education, these are the first educational escape rooms that specifically addresses the field of telecommunications engineering.

Keywords: Telecommunications Education; Active Learning; Educational Escape Rooms; Modulation;

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1. Introduction

Active learning, as distinct from passive learning, comprises of a broad set of pedagogy which requires active participation of students in the classroom (in contrast to listening and memorising coursework) [1] [2]. Active learning approaches include problem based learning (PBL), laboratories, peer learning, in-class clicker quizzes and game-based learning (GBL) [3]. Active learning is a growing trend across many educational sectors and has been demonstrated to improve student engagement, understanding and collaboration [4] [5].

Gamification and game-based learning are two related active learning implementations. Gamification describes adding game elements (e.g. points, challenges, badges and leader-boards) to education [6]. Game based learning, or 'serious-games' refers to games which include embeded educational content. Trends of use for both gamification and game based learning are increasing as they have been shown to improve learner motivation and involvement [7] [8] [9].

Aside from the traditional theoretical lectures and simulations, the last decade has seen several advances in hands-on telecommunications engineering pedagogy. The use of problem and project based curriculum has resulted in significant student satisfaction [10] [11]. Similarly, a game based simulation was recently used to help students understand telecommunication business markets [12]. Two unique approaches within laboratories have involved virtual laboratories and the use of software defined radio to aide student understanding at a practical level [13] [14]. Two aspects often mentioned for each of these approaches is the improvement to teamwork and student engagement within the cohort of students.

'Escape rooms' are a live team-based game which is growing in prominence around the world. In the game, the players work within some sort of scenario (e.g. prison break, zombies, finding a formula) and complete their mock mission by solving a series of puzzles within a prescribed time interval (typically 1 hour) [15]. Since originating in Japan around 2007 escape rooms have spread rapidly around the world [16]. Escape room activities broadly appeal to males and females equally

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and have been used for corporate team bonding, date nights for couples and as a fun activity among friends [16].

Although they are referred to as an 'escape room', in reality a traditional escape room often contains more the one room. More recently the escape room game experience has been adapted into board-games and computer based activities (e.g. EXiT, Unlock!). This adaptation allows for the scalability required for use in larger educational environments [15].

Educational escape rooms are game based learning activities, where concepts to be learnt or revised are embedded within escape room puzzles. Currently educational escape rooms have been run in physically setup rooms [17], as online simulations [18], as a tabletop 'lockbox' experience [19] or using an electronic decoder/validation device [20] [21].

Although educational escape rooms are a recent concept, they are rapidly growing in scope. Recent examples of educational escape room activities have been described for pharmacy, computer science, engineering, nursing and chemistry [22] [23] [24] [25] [26]. Studies have reported that learners typically report high levels of enjoyment, teamwork and engagement within the educational escape room activities [27] [28].

In this paper we extend the escape room concept to create the first two educational escape rooms targeted towards teaching telecommunications engineering. Telecommunications engineering is a board discipline which comprises of computer networking, digital signal processing and fundamental concepts of modulation, signal propagation and fundamental physics [29]. The escape room activities described in this paper are broadly designed to apply the following telecommunications concepts: modulation, attenuation, data integrity, error correction and data encoding.

This paper is structured into four sections. In Section 2 we discuss our game based learning methodology, including how the escape room games are played and also the actual puzzles used within the game. In Section 3 we present our escape room beta testing results and analysis with academics and professional engineers. Finally, our concluding remarks and future work are discussed in Section 4.

2. Methodology

In this section we detail the puzzles that we have implemented in our two escape rooms. We describe both the context of the puzzles, explain a truncated sample of each puzzle and how the solution to the puzzles can be determined. Each of the escape rooms was designed to occupy approximately 50 minutes of class time and will be run as an open-book activity – allowing students to find the resources they require to solve problems when they arise together in small groups of 3-4.

Within the classroom we normally use a physical decoder box as described in [21]. In this study we were more concerned with evaluating the puzzles rather than the decoder box interface, hence we have opted for a simple online interface which, although slightly less engaging, is a more COVID safe approach.

Each of the puzzles uses multiple variants of the same question. Hence, when a group has worked out how to solve the puzzle, they need to apply their solution several times which helps in reinforcement of the concepts and sharing the problem solving across the team. Each of the puzzles also includes a narrative which builds engagement as an activity, but doesn't specifically have learning elements embedded within it. Given we are primarily concerned in evaluating the puzzles, we have omitted the narratives from this paper, suffice to say that they involve escaping from a secret laboratory which is about to self destruct.

2.1. Escape Room 1

Escape Room 1 consists of three puzzles: Parity, Longitudinal Redundancy Check (LRC) and Modulation. These puzzles are each described with examples in the following sections.

2.1.1. Parity

Parity is a simple data integrity measure where a parity bit is assigned to each byte of data. This parity bit is chosen so that the resulting number of 1's is either an odd or an even number as agreed in the communications protocol.

In the parity puzzle students are provided with a table full of lists of 9-bit binary strings (one list is shown below) and a ASCII table.

- 010001101
- 010001100
- 010001101
- 010111101
- 010011110
- 010101011
- 010001000
- 010100100
- 010100101
- 010111101
- 010001110

A cryptic clue is provided as follows: *Now this puzzle is rather odd. Possibly there is some data corruption happening here and that is where the answer is hiding – can you find it in time?*

To solve this problem students need to look through each of the bit-strings and identify bit strings that have an odd number of bits (hence meeting an odd parity test). All other bit strings are even. In odd-parity this would indicate an error and hence these can be discarded. When these odd bit-strings are identified, the parity bit (last bit) can be removed and when converted to hexadecimal the ASCII table can be used to decode a specific number. In the example we have:

- 0100 0110 0 $\rightarrow$ 0x46 $\rightarrow$ F
- 0100 1111 0 $\rightarrow$ 0x4F $\rightarrow$ O
- 0101 0101 0 $\rightarrow$ 0x55 $\rightarrow$ U
- 0101 0010 0 $\rightarrow$ 0x52 $\rightarrow$ R

2.1.2. Longitudinal Redundancy Check (LRC)

The second puzzle results in the computation of an XOR based longitudinal redundancy check (LRC) on a block of data, although students don't know this at the start. LRC's a are more robust form of error detection compared to parity and have less transmission overhead. They involve performing a sequential mathematical operation on each byte of data to generate a checksum which is appended to the end of the data.

Students are presented with a series of sequential hex bytes followed by an ASCII table. When the students look at each of the hex bytes in the ASCII table it will instruct them to compute the LRC checksum on all the data bytes provided. Students then need to convert all the bytes to binary and compute a sequential XOR as they travel through each of the bytes as demonstrated in Table 1.

The result for this truncated example (00101101b) is converted to decimal (45) and serves as the answer to our puzzle.

2.1.3. Modulation

Signal modulation, where a signal is combined with a carrier signal, is a fundamental communications concept for radio transmission. There are many different schemes of modulation including: Amplitude Modulation (AM), Frequency Shift Keying (FSK), Phase Shift Keying (PSK), Quadrature Amplitude Modulation (QAM) and On-Off Keying (OOK).

This puzzle presents students with a series of OOK, PSK and FSK encoded waveforms (a subset is shown in Figure 1). Students are not told what modulation method is used for each waveform and

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HEX	Decoded Value	Binary	XOR
0x43	C	01000011	01000011
0x6f	o	01101111	00101100
0x6d	m	01101101	01000001
0x70	p	01110000	00110001
0x75	u	01110101	01000100
0x74	t	01110100	00110000
0x65	e	01100101	01010101
0x20	<Space>	00100000	01110101
0x58	X	01011000	00101101

Table 1. LRC Computations.

are expected to decode each waveform into a binary and convert the string into a numerical character using the ASCII table.

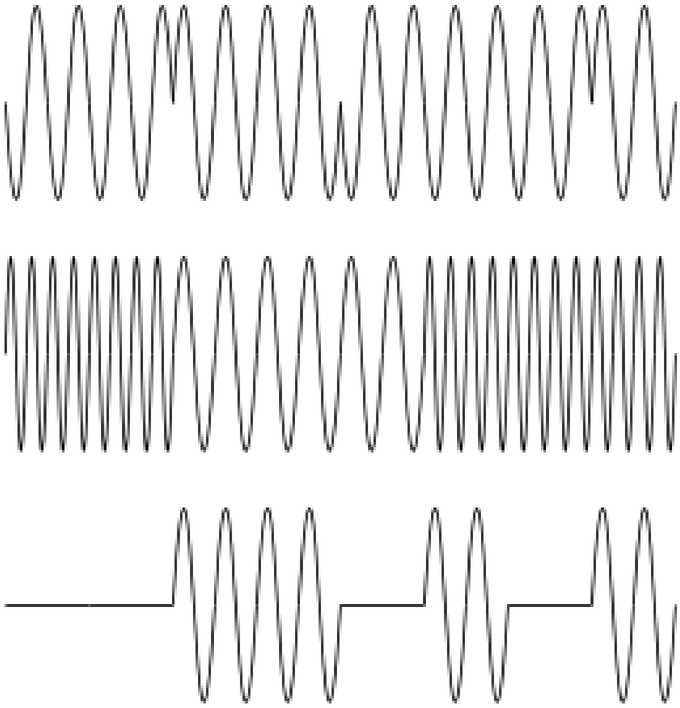

Figure 1. Modulation Puzzles using (top-to-bottom) PSK, FSK and OOK.

Each of the different modulation puzzles brings out a different element of how the signal encoding is used. For the top modulation signal (PSK), 0's and 1's are encoded in different phases so participants will need to work out which corresponds to 0 and 1 and will decode the value '00110001' which corresponds to 1. For the middle modulation signal (FSK) two different frequencies are used to represent 0 and 1. Hence, the decoded signal will be '00111000' which corresponds to 8. Finally, the bottom modulation signal (OOK) is a basic variant of Amplitude Shift Keying (ASK) where a carrier signal is used to encode 1 and no signal is used to encode 0. Hence, the decoded signal should be '00110101' which corresponds to 5.

2.2. Escape Room 2

Escape Room 2 consists of three puzzles: Hamming, UART and Radio Propagation. These puzzles are each described with examples in the following sections.

Bit Position	1	2	3	4	5	6	7
Value	P1	P2	D1	P3	D2	D3	D4

Table 2. Hamming(7,4) bit positions.

2.2.1. Hamming

Hamming codes are error correcting codes which allow single-bit errors in messages to be corrected based on redundancy encoded within the message. This puzzle presents students with a series of 7-bit binary strings (representing some even hamming(7,4) encoded data) and Table 2.

Hamming(7,4) encodes 4 data bits (3, 5, 6 and 7) with 3 parity bits (1, 2, 4) to allow the receiver to work out which bit, if any, have been flipped, and hence correct the error. To solve the puzzle students need to compute the parity for all three parity bits and deduce which bit (1-7) is in error for each of the encoded strings. Hence, the string '1010111' would result in the answer 6 as D3 is in error.

2.2.2. UART

UART (Universal Asynchronous Receiver/Transmitter) it a common communications interface used within embedded electronics. UART's for the basis of common protocols such as RS-232 and RS-422. UART's don't have a separate clock signal, send data in chunks (typically 8 bit) and include a start and stop bit for each chunk of data. Data chunks are sent in serial, one after another until the end of the message. UART's transmit data at defined baud rate (e.g. 9600bps) and use separate wires for transmit and receive.

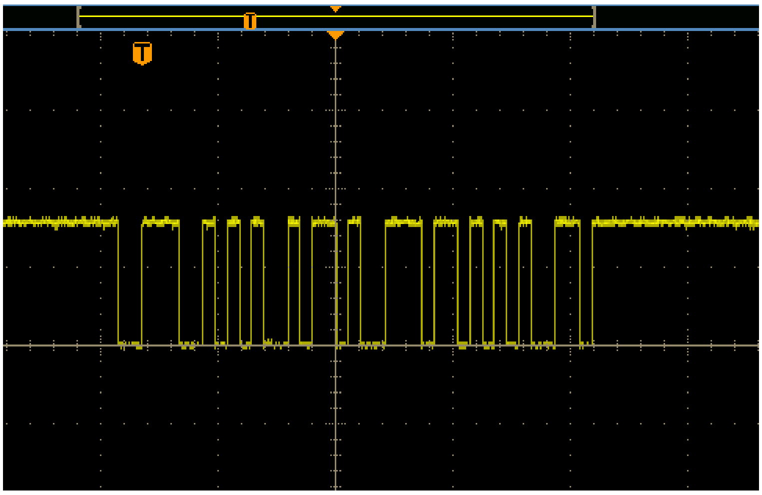

Figure 2. UART Puzzle which spells out "Nine".

This puzzle presents students with a data-stream of bytes sent via a UART and captured using a digital oscilloscope (Figure 2). To successfully solve the puzzle the students need to identify the position of the data (and hence the start and stop bits for each chunk), transpose the data (as the least significant bit is the first one transmitted), convert the data bytes to hex and finally decode the data bytes using an ASCII table. The puzzle consists of several UART wave-forms, each which encodes a different number which needs to be entered in order into the decoder box.

2.2.3. Radio Propagation

The final puzzle for this escape room involves computation and reasoning around Free Space Path Loss (FSPL). FSPL is a measure of attenuation of radio energy between a transmitter and receiver assuming an obstacle-free line-of-sight path [30]. Assuming non-directional antennas, FSPL can be computed in dB based on antenna gain, distance, transmit frequency and the speed of light as described in 1.

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$$FSPL = 20\log_{10}(d) + 20\log_{10}(f) + \log_{10}(\frac{4\pi}{c}) - G_{Tx} - G_{Rx} \quad (1)$$

where, d is the distance in km, f is the frequency in MHz, c is the speed of light and G_{Tx} and G_{Rx} are the gains for the Tx and Rx antennas respectively.

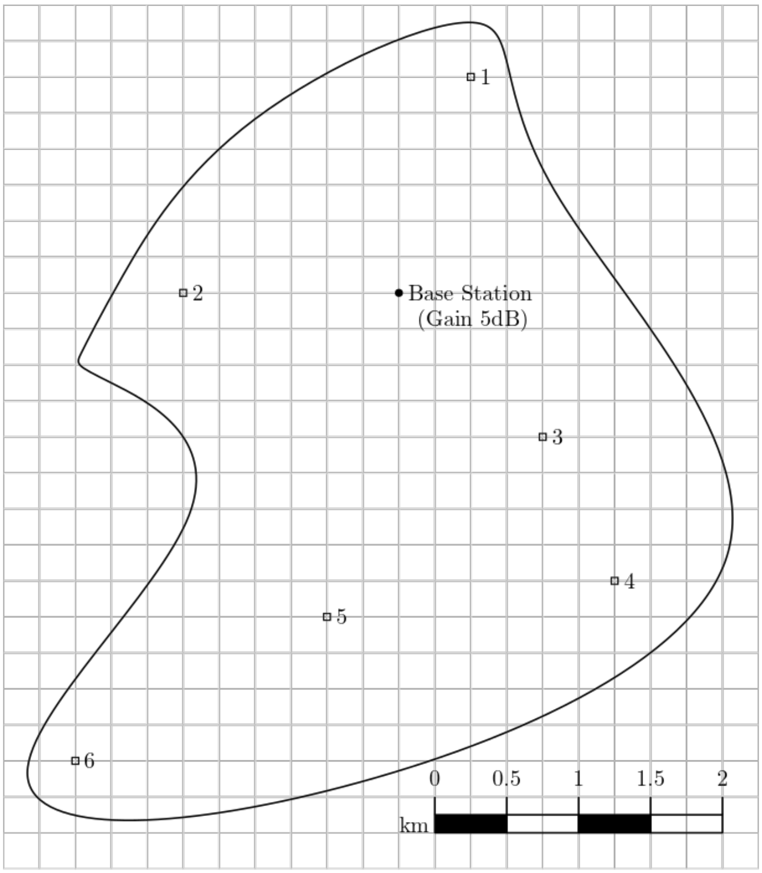

Figure 3. Scale map of island for computation of Free Space Path Loss (FSPL).

In this puzzle students are given a map (Figure 3) and a table which has parameters for antenna gain and frequency for each of the transmitters (1-6). Two frequencies which are commonly used within LoRa communications (433MHz and 915MHz) were chosen with a range of different antenna gains to demonstrate the significant effect of frequency on path loss. To solve this puzzle, students need to compute the Euclidean distance (using the scale) for each transmitter and then calculate the FSPL for each transmitter. Once all the FSPL's have been computed the solution is ordered from smallest to largest in terms of FSPL.

3. Evaluation and Results

In this section we present the results based on surveys and feedback recorded after participants completed each of the puzzles. A total time of 50 minutes per escape room was allowed for the activity.

We had two separate cohorts complete the escape room individually. The first cohort consisted of 4 academics who have a backgrounds in electronics engineering or telecommunications. This cohort was selected as they have significant experience in teaching and can provide an instructors insight into the activity. The second cohort consisted of 11 professional engineers. This cohort was selected as in some cases they had fresh memories of what is was like as student and can provide feedback on the activity in the current context it is used.

Each of the cohorts were provided with relevant lecture materials to answer each of the escape room questions. This was provided as the escape room activities are run in an open-book format and

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although our beta testers have a background in the area, their knowledge on the particular subject matter will likely be less at the forefront of their minds compared to the students who are just learning the material. The notes given to the participants are a subset of notes that will be supplied to all students studying the course.

For each puzzle participants were surveyed with a Likert scale based on how difficult they perceived it (1 = very easy to 5 = very difficult), how much they enjoyed it (1 = strongly disliked to 5 = strongly liked) and how much they think they learnt (1 = very little to 5 = a lot). The results from participants for each of these puzzles are shown in Figures 4, 5 and 6.

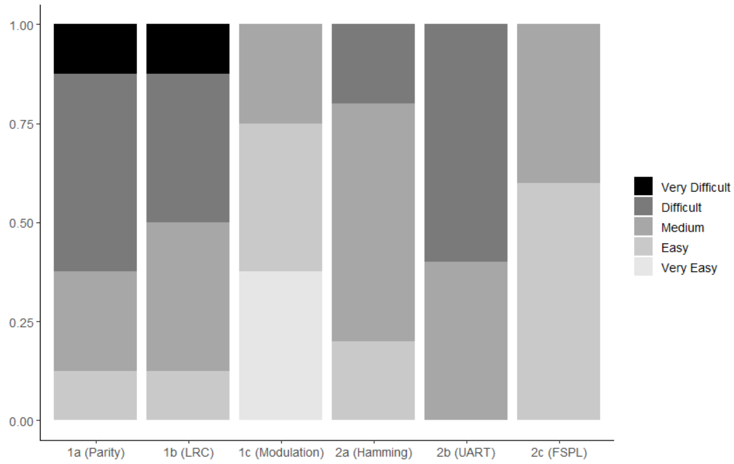

Figure 4. Survey results rating puzzle difficulty.

The Parity and LRC puzzles were judged the hardest (although some respondents said they were still easy). Both of these puzzles required lots of computation, took longer to solve and so are better suited to using teamwork. Several testers required some clues on the parity puzzle to get started with it being conceptually confusing which bit was the parity bit and what they meant to do with it.

In contrast the Modulation and Free Space Path Loss puzzles were rated as the easiest. We expect this was because they were a little less cryptic (although the modulation puzzle still required participants to work out which frequency and phase corresponded to a zero and one) and faster to complete. As a general rule we try to keep the easiest puzzle for end (and the most difficult puzzle near the middle) as towards the end participants are often racing the clock and may start to get weary.

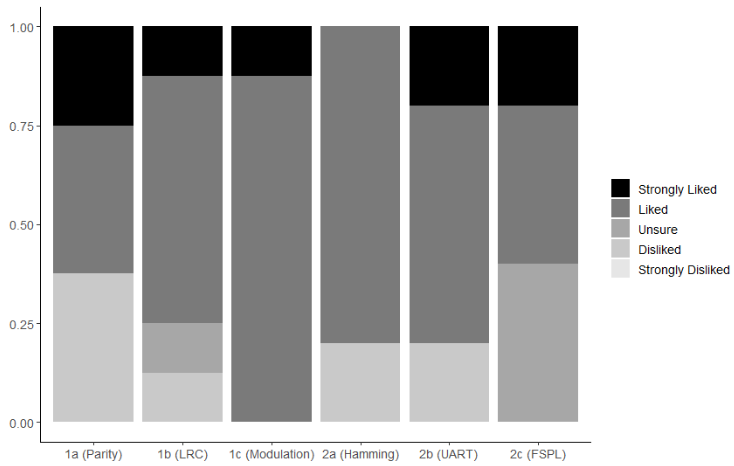

Figure 5. Survey results rating puzzle enjoyment.

In relation to the puzzle enjoyment we are encouraged that no-one strongly disliked our puzzles, but several testers did dislike the parity puzzle. Their comments suggest this was in part working

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out the trick to solving the puzzle and in part that lots of repetitive operations that were required (specifically in number base conversions and ASCII look-up). This repetition is deliberate (to give an opportunity for teamwork and practice) and will be less apparent when tasks are completed in teams rather than individually (as our beta tested completed them). Within the classroom clue delivery is automated (every 5 minutes one digit is revealed) which should also help teams of students who are stuck trying to get started. One beta tester stated that they used an Excel spreadsheet and another wrote custom Python scripts to solve the first two puzzles in Escape Room 1. This software approach is actually the same approach we used in designing the puzzles.

We note that the modulation puzzle was the most liked puzzle (all testers either liked or strongly liked) which suggests the level of difficulty and clarity was about right. The Hamming and UART puzzles, both of which required a fair bit of revision on the part of our testers were also strongly enjoyed.

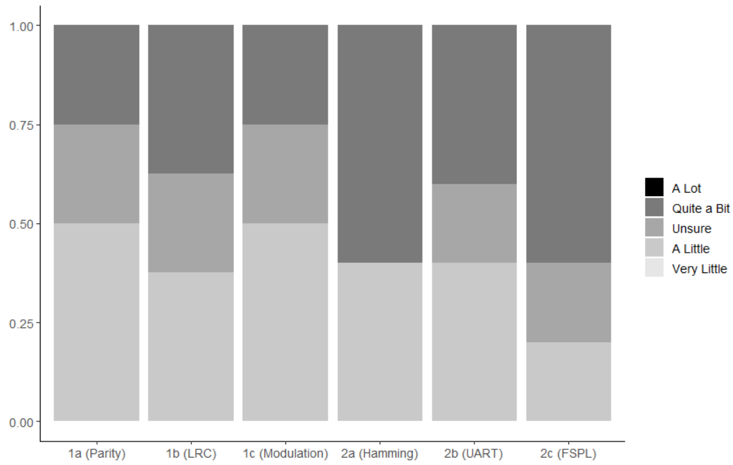

Figure 6. Survey results rating puzzle learning.

In terms of perceived learning within the escape room, all survey results for all puzzles varied between 'a little' and 'quite a bit'. Given that most of the testers will have encountered many of this concepts within their engineering studies, we expect this largely to be long term revision or re-familiarisation. The Hamming and Free Space Path Loss puzzles tended to claim more learning, although all puzzles had at least some participants saying they learnt 'quite a bit'.

Participants were also surveyed on some wider questions about how they felt about the activity with the results shown in Figure 7.

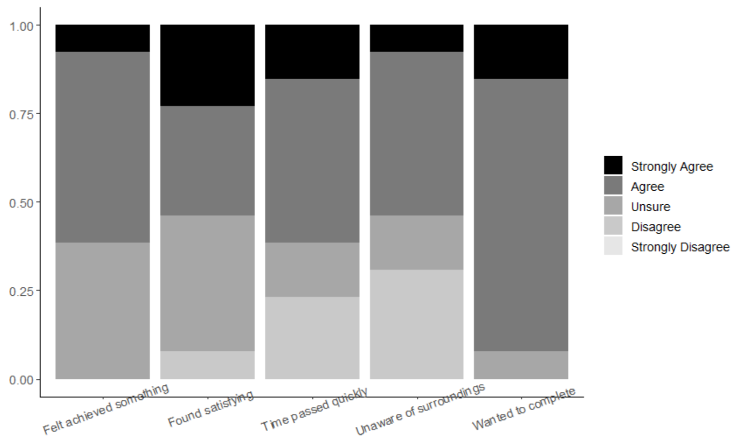

Figure 7. Survey results on tester perceptions.

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Over 60% of testers felt a feeling of achievement (agree or strongly agree) in working through and completing the escape rooms. We expect this figure to increase in the classroom as a group activity and the teamwork element comes into play. Likewise, most testers found the activity satisfying, with the few dissenting respondents pointing to excessive repetition (which will be less apparent working in teams) and the need for a more satisfying conclusion to the narrative (which is easier to deliver in a face-to-face environment).

Just over half of the of respondents noted the time (50 minutes) seemed to pass quickly and that they became unaware of their surroundings. This suggests that these participants may have entered some level of flow and became quite absorbed in the activity [31]. Based on other escape room activities we postulate this will be enhanced for the in-class team based version of the game.

Finally we were encouraged to see the very high motivation level of the testers in 'wanting to complete' the escape room challenges. The testers were not offered any incentives and so we see a positive inherent motivation driven by the game based learning.

In addition to the survey results, the beta testers provided some helpful feedback on how they solved the puzzles and further improvements. The parity puzzle consisted of columns of data, but two participants elaborated that they immediately started working across the rows rather than down the columns, hence we will include a gap between each of the columns to make it more obvious.

Beta testers who were not familiar with the escape room format gave feedback that they tended to struggle more – specifically in getting started and knowing what was required of them. This suggests a pre-activity briefing or practice is required. Some mentioned the puzzles were a little too cryptic for them and some more clarity could be given (e.g. breaking up the data an parity bits in the first puzzle). We don't plan to make the puzzles much less cryptic as students will have the benefits of freshly covering the material in detail, teamwork and having an instructor on-hand to give hints as required.

One common element of feedback from almost all testers was that the activities (though challenging) were fun and they expect will resonate well with students.

4. Conclusion

In this paper we present and discuss the first educational escape rooms designed for teaching telecommunications engineering. These six puzzles, which formed two separate educational escape rooms were completed by a series of beta testers from both academia and graduate engineers. The activities are designed to be run in an open book format and so our participants were provided with extracts from lectures which covered relevant material.

Participants were surveyed at the conclusion of the activity and provided significant feedback across the different puzzles. The results from our beta testers suggest the intrinsic motivation for engaging in these activities is very high, and although some puzzles were quite difficult, the level of enjoyment was also very high.

Given the positive feedback we are keen to introduce this activity to the classroom to provide our telecommunications engineering students an engaging, team-based active learning platform. When these activities are integrated into the classroom we plan to perform similar surveys with students, record analytics (time for each puzzle and incorrect guesses) and correlate escape room performance with exam performance for similar questions.

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